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Engineer
School

March 1917

Construction of Dugouts

Textbook.

Captain Billiard

*Army Group
of
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U. S. Army Military History Institute

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PROPERTY OF US ARMY

GENERAL VIEWS

The defense of a position implies the necessity of giving to the defenders the means of remaining on the battle ground, in the best conditions of material and moral security, notwithstanding the projectiles and machines of all kinds which the assailant may use against them.

The experience of recent battles, especially those of Verdun and the Somme, has shown the ever increasing intensity of the destructive action which the artillery is capable of producing. The continually increasing use of pieces of larger calibre; firing more and more powerful explosives, the great improvement in the methods of terrestrial and aerial observation, make the destruction of any superficial arrangement and any insufficiently protected shelter absolutely certain, if their position has been discovered.

To these means of destruction must be added the asphyxiating gases, whether coming from special machines or from the Artillery, and against which the defender must be protected.

The shelters to be built in the defensive positions will thus have to fulfil the following conditions :-

1. Be proof against a bombardment preceding an attack.
2. Be very difficult to observe, even during their construction.

3. Offer the best habitable conditions.

4. Protect the occupants against the action of deleterious and asphyxiating gases.

Making the shelters proof against a methodical bombardment will be obtained by constructions capable of resisting the effects of the projectiles usually employed to destroy dug-outs, that is high power ^{m/m} 210 shells and larger calibers.

But the power of these larger shells is so great, that it would necessitate very important constructions, usually difficult to make. So it is best, in the field construction, to limit ourselves to protection against the high power 210 shells, and that will give a sufficient security in most cases.

It is only in cases where shelter will have to be made in works offering an important and clear object to the ennemy, such as certain localities, the defenses of a point that must be passed, a bridge-head, etc.. that we will seek for protection against 305's, 380's and even 420's.

The examination of the effects of artillery projectiles has lead us (in a previous study, to the calculation of the necessary protective thickness, the results are summarized in the following tables.

Table I

UNDERGROUND - DUGOUTS

Caliber.	Explosive Charge.	Coefficient of the ground.	Thickness to be given to the roofs of dug outs.	Depth of Penetration.	Place of the experiences
210 high charge	18 kgs.	2 3	6.50 5.00	3.00 m 2.50	Verdun Mailly
305	35 kgs.	2 3	8.50 7.00	4.50 3.75	Verdun
380	68 kgs.	2 3	8.50 7.00	3.50 3.00	Verdun
420	106 kgs.	2 3	14.50 12.50	8.75 7.50	Verdun

SPACING OF ENTRANCES.

8 to 10 meters for the 210. 10 to 12 meters for the 380.

14 to 16 meters for the 420.

Table II

SURFACE SHELTERS.

1st Type.

Caliber.	Topcover for a - 2.50 meters			Sidewalls.		
	Vault with a 2.50 meters opening.		Slab 2.50 meters in length.	Ordinary Masonry.	Special Concrete	Reinforced Concrete.
	Ordinary Masonry.	Special Concrete.	Reinforced Concrete.			
210	2.00	1.50	1.00	1.25	1.00	0.75
305	2.25	1.75	1.25	1.50	1.25	1.00
380	2.50	2.00	1.50	1.50	1.25	1.00
420	--	--	1.75	2.00	1.75	1.75

2nd Type

Caliber.	Reinforced Concrete Bursters	Broken stones or sand.	Interior lining	
			Ordinary Masonry. 1.	Special Concrete 2.
210	0.75	1.00	1.00	0.50
305	1.00	1.00	1.00	0.50
380	1.25	1.00	1.00	0.50
420	1.50	1.00	1.00	0.50

We will now study successively the underground dugouts and surface shelters and see how to realize in their construction, the general conditions enumerated above.

Part. I

Underground dugouts.

Chapter One

1.- CHOICE OF THE GENERAL PLAN.

The choice of a plan for a dug-out will depend on its use and location (i.e. first-line dug-out for Infantry, for reinforcements, commanding posts, dressing-stations, machine-gun positions, etc..)

The Underground dugouts work being generally a difficult job, because of the time and the men it takes, one should always, by a well thought out choice of the situations and their distribution or general arrangement, adopt constructions that will necessitate the least labor.

In some cases, the construction of the dug out must be progressive, that is, allow for its occupation before its completion. The general arrangement of the rooms and communications with the outside must then be so planned that the occupation of the dug-out would not prevent its completion.

We will take up successively the outlets and the main bodies of the dug outs.

2.- ARRANGEMENTS OF THE OUTLETS.

The entry ways, always at least two; and three if possible giving and entrance and exit to the dug outs, must satisfy the following conditions.

A.- RAPID AND EASY MOVEMENTS.

- B.- REDUCTION OF THE POSSIBILITY OF AN OBSTRUCTED ENTRANCE
Weakest part of the system.
- C.- EFFICACIOUS DEFENSE IN CASE OF AN ENEMY RAID.
- D.- RESISTANCE TO THE STATIC AS WELL AS DYNAMIC ENERGIES,
CAUSED BY THE EXPLOSION OF PROJECTILES.

These communications can be made by galleries or by shafts.

GALLERY OUTLETS.-

A. MOVEMENTS.- Movements in a gallery outlet will be much easier if the slope of the floor is slight and if its cross-section, in a vertical plane, will allow for the passage of an armed and equipped man. The height of the gallery measured vertically, must not be less than 1,80 metres for a 2/3 slope; it must be 1,90 metres for a 1/1 slope.

The amount of the slope will be determined by the local topography and the depth of the dug out; but in a practically horizontal terrain, it is well to adopt a 1/1 slope, as that will allow the following advantages:-

1. REDUCTION OF EXCAVATION AND SIDE-SHEETING.

The difference in the volumes of earth removed from a 1/1 and a 2/3 slope both leading to a dug-out at a depth of 9 meters is about 9 cubic meters.

2. REDUCTION OF VULNERABLE LENGTH.

The difference in the levels reached by a gallery of 1/1 slope and one of 2/3 slope is 0,33 meters for a horizontal distance of 1 meter; the thickness of earth above the gallery thus increases very rapidly and favors the attaining of the conditions of resistance imposed upon the descents.

The 1/1 slope must nevertheless be considered as the

limiting slope both because of the difficulties of climbing a steeper slope, and those that its execution would entail.

B. REDUCTION OF THE POSSIBILITY OF AN OBSTRUCTED ENTRANCE.

This will be obtained first of all by clearing away from the outer-entrance all materials that would, in case of a turning over of the ground, make a mask difficult to pass through; to this end, no lumber or log covers for the entrance will be made.

The protection will also be increased -

1. By commencing a gallery with an initial protection of at least 1 meter of "natural earth, that will be reinforced by the earth first excavated, or better, by two thicknesses of logs, or rails, or Bursters separated by 0,50 meters of earth. (See plates 1 and 2).

The best protection, when practicable, is given by a concrete mass completely surrounding the first two or three frames (See plates 3 and 4).

2. By placing the frames side by side for the first 4 or 5 meters of the incline.

C. DEFENSE OF THE ENTRANCES OF DUG OUTS.

The assailants, having arrived at the entrances of dug-outs, will try to reduce the resistance of their occupants by throwing inside grenades or burning liquids.

If all the entrances to a dug out are attacked simultaneously, it will be very difficult if not impossible, for the occupants to escape, unless relief comes from the outside in the form of a counter-attack.

The defense of dug outs must be planned in such a fashion

that the assailants will be unable to reach the entrances, but that if they should succeed, they can be driven back by a counter-attack made by the occupants of the dug out.


THE DEFENSE WILL THUS BE EXTERIOR.

This result will be obtained by creating :-

1. Immediately beside the opening, "posts" that are able to keep up curtain fires (barrage) with rifles and grenades, in the communicating trenches leading to the dug outs;
2. OUTLETS that can be concealed until the very last moment, and from which will issue the part of the garrison detailed to make the counter attack.

With dug outs provided with three openings this arrangement will be very easy (See plate 5- Col. Cernesson's dug out).

In the central gallery, two guard rooms will be built on a level with the other outer entrances; they can be reached by stairs, and must be as far as possible shell-proof.

The central gallery, coming out to the rear, will serve to make the counter attacks. Besides this, the entrances to dug-outs that have a "chicane" () in a vertical plane, can be used for an interior defense. The guard that is posted in the main body of the dug out, at a depth of 8 metres, dominates the lower story (10 Mtrs deep) sees the adversary arrive there and can hit him

with his grenades, while the raider finds himself in very unfavorable conditions to use his weapons, also the grenades thrown in from the outside explode on the lower floor, without hurting the men in the main body of the dug out.

The constructions that have just been described are typical, and though they permit the defense of the outlets, they are incon-

veniently difficult and expensive to make. It would be better, in most cases, to substitute for them the simpler arrangement called the "Bâtardeau" with interior defense. (Plates 1 and 2).

It is composed of, (for a protective depth of about 4 meters of earth) a floor of 2,50 meters, able to receive, after completion of the dug out, a splinter screen around which the gallery will make a double bend.

In this splinter screen will be left a loop-hole so that the sentinel can hold under fire the steps of the stairs; a little ditch covered with a movable woden step or stool will allow him to assume an easy firing position for covering the entrance and the first steps.

A little room for periscopic observations could be placed on this landing.

A grillage door could be fastened so as to swing down 2 to 3 yards from the entrance; the grenades that might be thrown against these by the assaillants would thus be stopped, and would fall into a little ditch where they would explode.

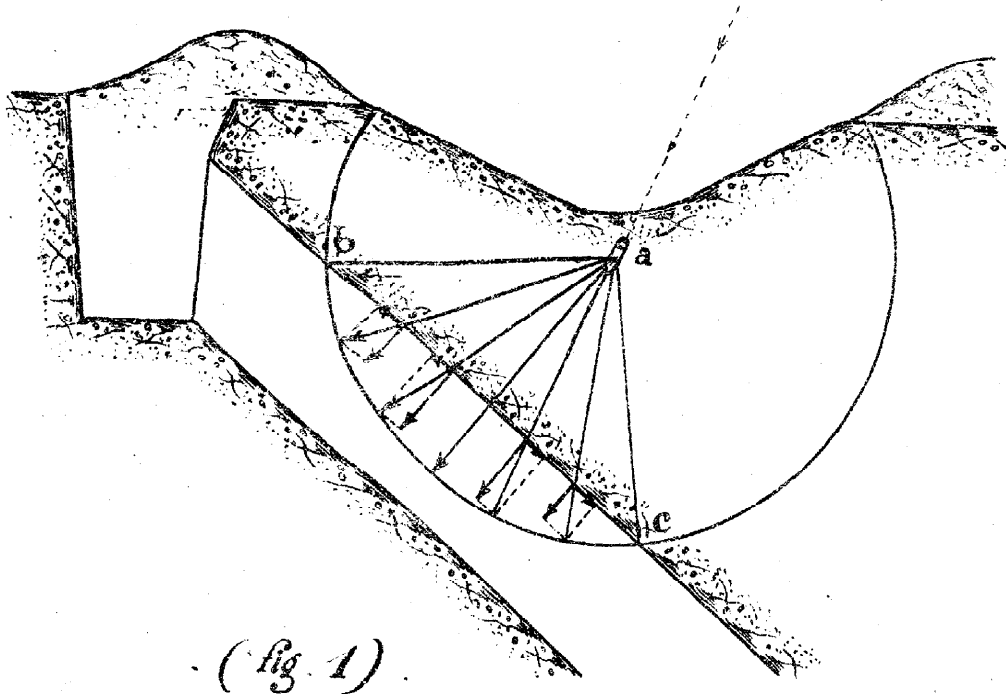
This arrangement of a turning gallery offers the advantage of diminishing considerably the effects of a projectile exploding at the entrance.

It has the inconvenience, however, of making the outlet rather difficult, and it is sometimes preferable, because of this, to place the bend at the bottom of the stairs, on a level with the main part of the dug out. The protection for the outlet

is in this manner better assured, but the defense of the outer entrance is made more difficult.

D. MAXIMUM RESISTANCE.

Let us assume that a projectile explodes over a descending gallery at given point A : - (Fig.1)



(fig. 1)

the forces that affect the gallery may be represented by lines that follow the radii of rupture produced by the explosion of the charge, that affect the ceiling of the gallery from B to C.

These effects may be considered as longitudinal and perpendicular to the gallery. The Pressure on the earth causes also resultant forces on the ceiling, which can, like the preceding ones, be divided into effects perpendicular and parallel to the gallery.

The longitudinal effects have a tendency to cause the turning over of the frames, and the perpendicular effects tend to cause the rupture of the cap sills and top

sheeting-planks of the frames by curving them in, and by compression of the pieces "normal" to the gallery. The turning over of the frames will be avoided by a longitudinal bracing appropriate to the kind of gallery used. The rupture of the cap sills and sheeting will be avoided by reinforcing the ceiling. (Choice of frames, use of a greater number, especially toward the entrance).

If the projectile explodes to one side of the gallery, there will be pressures that will have a tendency to deform the frames and even to break the stanchions. Precautions can be taken against these pressures by reinforcing transversally the frames and reinforcing the sides of the gallery (using a larger number of frames).

BRACING.

The galleries are at present timbered with ordinary frames, or with cases set, either vertically or perpendicularly to the slope. We will examine the resisting qualities that these different classes of linings offer.

a/ - GALLERY WITH ORDINARY VERTICAL FRAMES.

Let us consider a frame AB; (fig. 2) under the action of longitudinal effects, it will tend to turn over C.G.W., the earth's reaction in A opposing its turning over C.W.

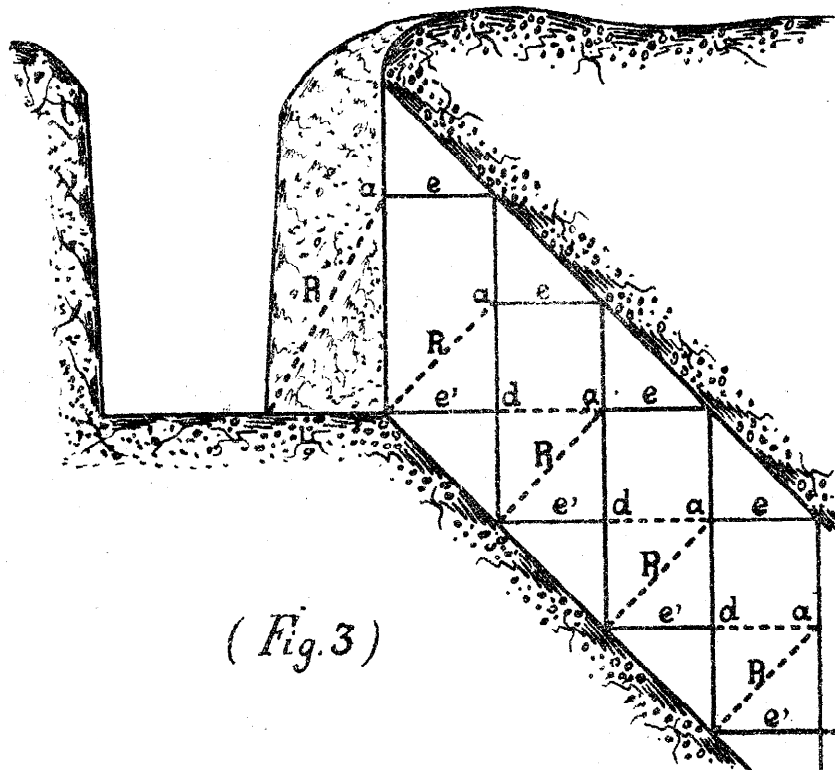
To prevent this movement we will need :-

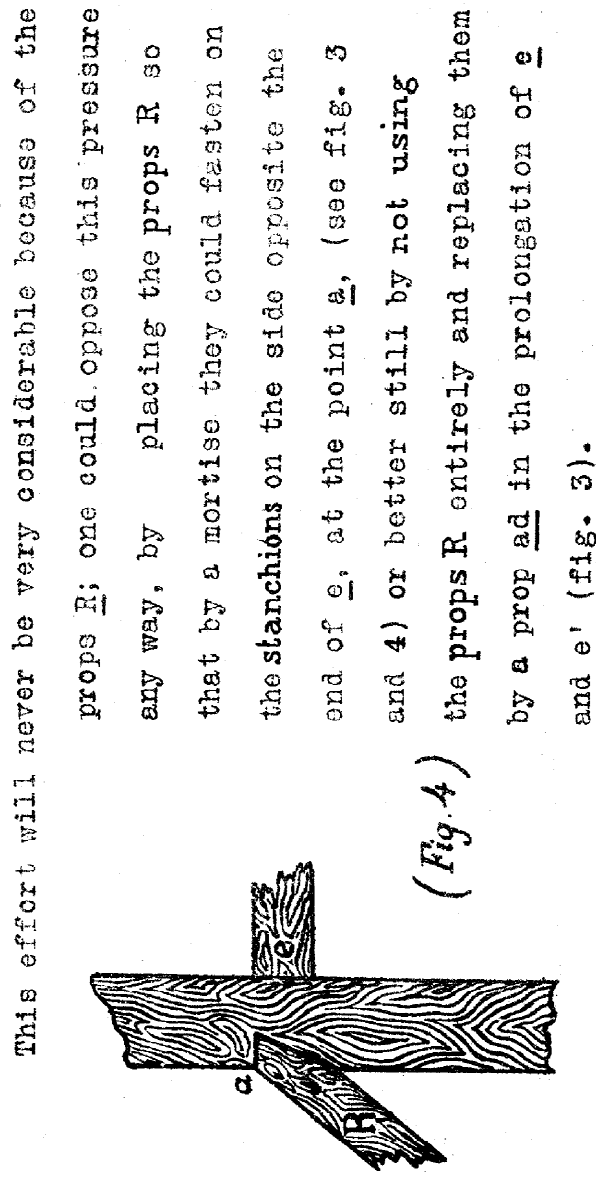
1st.- A horizontal prop a held first at the cap sill and upright at A, secondly on the preceding upright at a.

react on the earth again. This arrangement, besides impeding movements, is very vulnerable, and from that point of view alone it is impossible to allow the development of "bracing" to rest here.

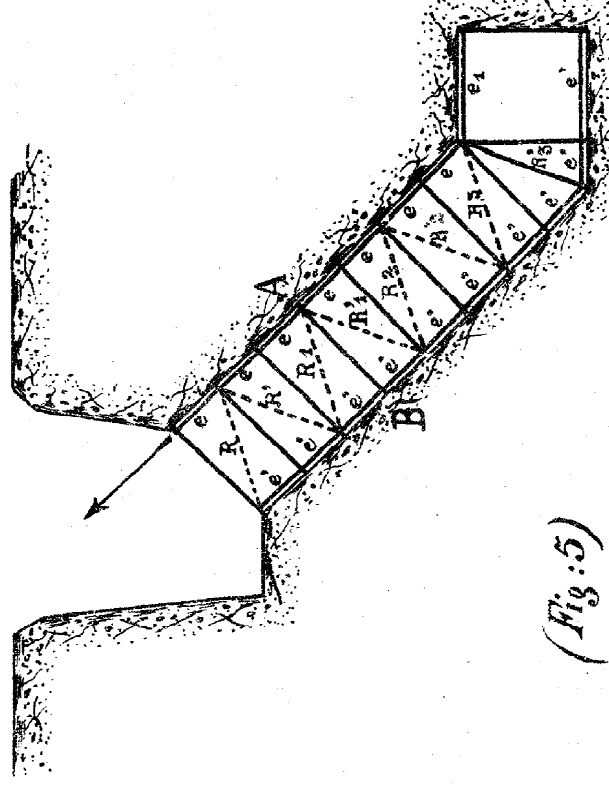
It must therefore be completed by props R_1 R_2 etc., practically perpendicular to the axes of the gallery, that will allow each panel to be self supporting, and that will contribute with the props e and e' to form in the gallery a rigid triangular system of framing.

If the slope of the gallery is steep, the upper horizontal props will be fastened to the stanchions at a certain distance from the cap sill, and could bend them. (fig. 3)





b/- Entrance of half-gallery-frames perpendicular to the slope (fig. 5).



The frame A B can, by the effects of the explosion, turn over CW. or C. C. W.; Bracing in each direction will

therefore be necessary. This will be assured by propping all the frames between each other with pieces e e', placed in the angles of the gallery, and attached to the sills and uprights respectively.

The bracing will not be complete unless a frame is established at the entrance, intended to bring to the earth the final effort of turning over C.C.W, and, when the work is finished, an abutment can be realized at the bottom part along "e₁".

By following the example of the first case, the bracing could be completed by the use of symmetrical props $R_1 R'_1$ etc..., but in this manner we cannot completely abolish the "slipping components" that will always act on the frames during the construction of the gallery through the effects of an explosion, or even the simple pressure of the earth.

Besides this, if this method of timbering has some imperfections, it has several advantages;- It diminishes the amount of wood needed and is rather easy to build in a very good soil.

c/- Gallery with vertical cases.

The working dimensions of these cases are the same as those of the common gallery, that is 1,85 or 1,90 meters high. They are usually built with 22/8 planks (ground sills and stanchions) and 23/11 planks (cap-sills). Compared with the frames of a common gallery of that height, the resistance of stanchions made of $\frac{8}{8}$ planks would be weaker; the resistance of the cap-sills will be practically the same, but on the whole, the resistance per meter of length is greater in the case of galleries built of cases.

By a process similar to that of the frames in vertical woodworks, the gallery will be braced by planks 4cms thick,

practically "normal" to the gallery, and fastened at the re-entrant angles of the woodwork at the floor and ceiling of the gallery.

(See plate 2.)

The gallery with cases has the following disadvantages; great amount of timber difficulty to assure a proper filling in of the sides and the ceiling, and consequently: - woodworks badly fitted to the earth. Nevertheless, because of its easy construction, it can be recommended for Infantry troops unused to woodwork, and in good terrain only.

d/- Gallery with cases perpendicular to the slope.

Used on some parts of the front, this method is not recommended because of the difficulty, if not the impossibility of its bracing and its insufficient filling up of the empty spaces around it.

This forms a loose construction, without any adherence to the surrounding earth.

CONCLUSION.

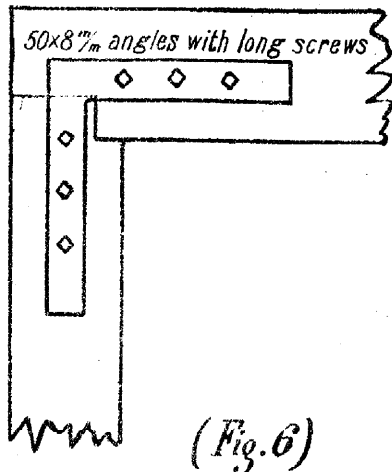
1st. Cases perpendicular to the slope must be cast aside.

2nd. Vertical cases, though forming a wood-work insufficiently bound to the earth, can be recommended for infantry troops by whom they can be easily placed.

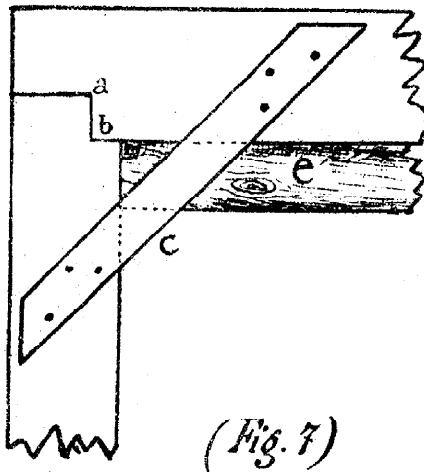
3rd. Ordinary frames perpendicular to the slope must only be used for very heavy slopes, in very good terrain and when we seek for a rapid and economical execution of the work.

4th. The preference rests with the vertical timber-work frames, that well reinforced, form an excellent wood-work, perfectly joined to the surrounding earth.

TRANSVERSE BRACING.



To prevent the deformation of frames in a transverse direction, the junction of the cap sill and stanchions can be braced by angles of strap iron, of 50 mm/8 mm, fastened with wood-screws. This joint will be still stronger if a slot is cut in the frames into which the iron plates can fit. (See fig. 6)



But the above process is usually difficult to realize in the first lines. In this case a simpler transverse reinforcement could be employed, consisting of four braces "c" assuring the rigidity of the angles of the sills and stanchions, and of horizontal prop "e" fixed under the cap-sill. This piece will also

increase the resistance of the stanchions, which will not in this condition, as might otherwise happen, break along the prolongation of the vertical

face "a b" (See fig. 7)

CONCRETE FRAMES.

Our resources in wood being very limited, the use of reinforced concrete frames has been suggested instead of ordinary mine frames.

The "Technical Section of the Engineers" has built frames for "Grand Galleries" and "Common Galleries", and also "oval" frames, the different parts of which can be put together with bolts. (See plates 6 and 7).

From experience at the Melette polygon, it has been found that the wooden frames are stronger than those of reinforced concrete. (About double the resistance : a "grand gallery" frame of reinforced concrete broke under a uniformly distributed weight of 18 tons). The pressure of the ground caused by the action of heavy frosts in January-February 1917, caused, in galleries built with reinforced concrete frame, a bending of the stanchions almost to the point of a rupture, causing a crumbling of the concrete and an exposure of the steel in many places; the wooden frames, under the same conditions, suffered only an insignificant bending not reaching a point of permanent deformation.

The reinforced concrete frames are also difficult to transport and require great care, as the steel can be exposed at the slightest shock. Moreover, the construction of inclined galleries is made difficult by the triangular form of the cap-sill.

Lastly, wood-works, based on the friction between wood and concrete does not seem to have given satisfactory results.

To resume, the use of these frames seems to be limited to excavated shelters open at the top, under conditions that the frame is kept tight during construction, and of reducing to a minimum the movements and successive handlings necessary to bring the materials to the place of use

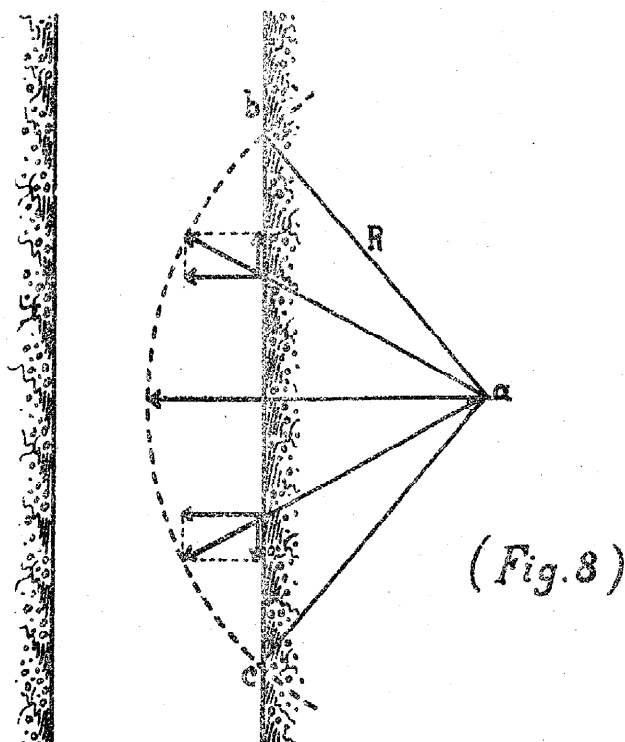
SHAFT OUTLETS.

Among all outlets, the shaft is the one that needs the least work, but if it is less exposed than an incline, it is unfortunately easier to put out of service. Moreover, it limits the traffic and must be absolutely avoided as an outlet for a dug out of great capacity. But in certain cases, the use of the shaft is necessary, for example to increase the number of attacking stands in important dug outs, to permit one to enter, or for lighting the commanding posts or to provide entrances to machine-gun emplacements for bombing and, for observation posts, etc...

In the last case, the shafts will be of a small depth, and joined to the dug-out by an inclined gallery.

To provide in these shafts for a relatively easy passage they could be fitted with one of the arrangements mentioned below.

1/- Shafts, 1,04 X 1,04; (or 1,20 X 0,80 with steps on the small side). The men climb by spreading the legs and placing the feet alternatively on each step, assisting themselves with their hands if necessary. This arrangement is to be used particularly for the outlets leading to bombing-posts as the supplying of grenades is easily done through the central part of the shaft, either by an improvised elevator or by a chain of men (See plate 8)



2/- Shaft of 1,04 X 1,04 or 1,50 X 1,00 with stairs parallel to the little sides, or winding staircase. These arrangements take more time to construct than the first, but the ascent is easier; it is especially convenient for outlets for machine-gun emplacements.

BRACING A SHAFT.

Let us suppose a projectile exploding at "a"; the forces that affect the well may be represented by forces that follow the radii of a sphere of compression produced by the explosion of the charge, and that affect the sides of the shaft from "b" to "c". These forces may be considered as forces parallel and normal to the axis of the shaft.

The first forces tend to lift up the frames or to lower them; they will be opposed by placing vertical logs between the frames at the angles of the shaft.

These logs will transmit successively the lifting efforts to the top frame, that will have to be secured with a proper length (at least 1 meter) of buried bracing. (See Plate 10) .

The bracing in the vertical direction will be completed by making angle-irons C C C C that will assure the rigidity of
1 2 3 4
the frame.

The forces that are normal to the shaft will tend to break the lining by bending, or by compression of the different pieces of the frames. This will be opposed by using well-chosen frames, and by placing them nearer together for the first few meters of the shaft.

In addition to this, to prevent the vertical props from sliding towards the center of the shaft, they will be secured by cleats nailed to the frames. (See Plate 11).

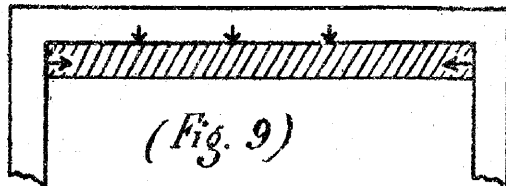
THE MAIN BODY OF THE DUG-OUT.

Two cases are to be considered :-

1st-case.- The materials must be carried by hand for a long distance, (case of a fighting sector, for instance), or the command requires the construction of the dug-out in a very short time. In this case the dug-out will be composed of two large parallel galleries. This arrangement has the following advantages :-

1°/ Easy transport to the site of the work ; each piece of wood can be carried by a single man, and through the communication trenches.

2°/ Rapid work; Because the section is half as large



as that of a "grand gallery" and as duplication of the first gallery can be rapidly made because of the possibility of working in several places at a time (in medium ground). (Fig. 9)

3°/ All movement inside the dug-out and consequently at the outlet is very easy. The interior arrangements can be made in one of the galleries, leaving the other free for moving. (Plate 12, left side). A less compact arrangement can be managed, by placing the beds in tiers between two frames, perpendicular to the axis of the dug-out, but this is detrimental to easy movement. (Plate 12, right half).

Precautions to be taken :

1st. - REINFORCE THE BODY OF THE DUG-OUT IN A LONGITUDINAL DIRECTION, by props at the lower and upper parts, joined at the same time to the cap-sills and stanchions, and to the ground sills and stanchions.

2nd.- INSURE THE CONNECTION BETWEEN ADJOINING STANCHIONS by four diagonal braces $a_1b_1c_1d$ on the sides perpendicular to the axis of the dug-out.

2nd.case.- The material can be easily brought to the site of work; in this case the following different types that we are going to examine rapidly, can be built;

1st/ BODY OF THE DUG-OUT FORMED OF ONE OR TWO GALLERIES
1,33 meters wide.

As the camp beds, disposed longitudinally, occupy a width of 0,65 meters, supports included, a width of 0.68 is left for passage for a dug-out of small capacity. In the case of a squad's dug-out, the outlets are 15 meters from axis to axis (see plate 13.) A dug-out for half a platoon can be made either by two parallel galleries separated by 2 meters of plain earth (see plate 14) or by the juxtaposition of two "squad" dug-outs; this will allow us to have three galleries, the central one coming out in the rear, and the other two towards the lines. (see plate 15).

2nd/ BODY OF A DUG-OUT MADE BY A GRAND GALLERY.

In this case the beds can be placed either parallel to the body of the dug-out with a central passage of 0,70 meters or perpendicular thereto, with a lateral passage of 0,60 meters. (In either case, the uprights that hold the beds help to support the cap-sills of the grand-gallery. (See plates 1 and 2.)

3rd/ BODY OF A DUG-OUT COMPOSED OF NICHES OF THE DIMENSIONS OF A GRAND-GALLERY OR OF A GALLERY OF 1,33 METERS, OPENING ON A CENTRAL PASSAGE OF THE SIZE OF A COMMON GALLERY OR OF A 1,33 METERS GALLERY. (See plates 16 to 19).

These dug-outs offer many advantages :-

- 1/ Rapidity of building when the central passage is made, all the niches may be worked on at once.
- 2/ Circulation and outlet made easy by the central passage.
- 3/ Better living conditions.
- 4/ Progressive dug-out, possible of being partially occupied before entirely completed.

4th. Dug-out for a platoon, as built in the 2nd Army by the M.D. Battalions.

This dug-out consists of two longitudinal, parallel galleries placed at different levels. The lower gallery is a common gallery giving access to niches of grand gallery or "1,33 meter gallery"

The upper gallery is 1,33 meters wide, and can be fitted with double decked camp-beds placed longitudinally. (See plate 19).

MACHINE-GUN EMPLACEMENTS

The instructions of November 24th, 1915, on tactical use of machine-guns, recommends an emplacement in the open, composed of an excavation simulating a shell-hole, that is reached by a shaft or a gallery connected under ground with a dug-out, where the machine-gun is kept and the men live.

The opening of the shaft or gallery must be provided with a proper concealment. The machine-gun is set in firing position at the last minute, without protection, or with an ordinary parapet shield. (See plate 20).

The same instruction prescribes placing the machine guns at the end of the gallery starting from any cover whatever and opening on a steep slope, by a road side or a rail-road bank, etc..

When the machine gun is kept in this manner at the end of a gallery, it will be found necessary to build a mask-wall to protect the personnel and material. This will be accomplished by ending the gallery with 3 or 4 sections of "Grand-Gallery" in which concrete will be poured, leaving in the middle the necessary room for placing the machine-gun. (See plate 20) Besides this, the loop-holes and outlets must be concealed.

Similar arrangements can be used for automatic rifle-men, Bombing posts, for infantry for "V.B.'s" (Viven Bessières Rifle grenades) and for sentinels. The grouping by subterranean communications of these defensive organs, permits the organization of centers of resistance, having a considerable defensive capacity,

since they permit, by the rational use of all the specialities of which Infantry is now composed, a great density of fire; moreover they are difficult to locate, and guard all their value even after a violent bombardment. Plates 21 and 22 give examples of similar "supporting points" supposedly established between the observation trench and the line of resistance, and at such a distance from each that an artillery preparation made on one of them, or on both, would probably not destroy the positions.

The building of this subterranean "supporting point" will necessitate very important work; in the second position, this work will be facilitated most of the time by the possibility of making numerous surface attacks and using mechanical digging-machines (compressor-plants, electric drills, etc..) In the first position it will generally be more delicate, though the presence of numerous communication trenches between the observation and resistance trenches will contribute to facilitate the construction of the underground system, after the completion of which outlets will be established allowing the defenders to reach their fighting-posts without delay.

POSTS OF COMMANDING OFFICERS.

The deep dug-outs intended for the commanding officer and staff will differ from the others only in the interior arrangement of the rooms; these will be principally composed of recesses coming into a passage of common gallery size in such a manner as to insure the independence of the different rooms. The number of these will vary with the nature of the command; following table gives general data on this subject.

	Commanding Officer.	Staff or detached Officer	Liaison or special services officers	Observation rooms	Kit-chen	Tele-phone Central	Electric motor room	Orderlies acting as liaison agents	Total number of rooms
Batalion	1	1	-	1	-	1	-	1	5
Regiment	1	1	2	1	1	1	-	1	8
Brigade	1	1	1	1	1	1	-	1	7
Division	1	2	3	-	2	2	1	2	13
Army Corps	1	3	5	-	2	2	1	2	16

Very often a Command will require a Post reduced to the strictly necessary number of rooms, so as to get into it quickly, and in order to economize labor and material. As a post of command

is always susceptible, during an offensive action, of being used by a larger number of officers it is necessary to make the plans so that after the building of the desired rooms it is possible to enlarge it.

Plate 23 gives a plan for a C.P. of a division; a certain number of C.P. 's of a similar type were constructed during the Somme offensive in 1916. It is built against a slope facing away from the enemy, and is composed of a certain number of "grand gallery" rooms, lighted by the daylight through loopholes, and provided with a "common gallery" circulating passage. In case of a bombardment of high-caliber shells, the different services can be immediately transferred to the dug-outs, that are reached by a series of inclines starting from the passage.

Para. 6 - DRESSING STATIONS.

These stations will be very much like the preceding structures, but they are composed of a smaller number of rooms, having generally

- 1 room for the doctor,
- 1 room for the personnel,
- 1 recess for medicine,
- 1 room for bandages,
- 2 rooms to hold the wounded until they are removed

The post must also have an arrangement for rapidly and gently carrying the wounded up and down. (See plate 24).

Para. 7 - OBSERVATION POSTS.

These posts may be built as follows : (see plate 25)

- 1st. An "à la boule" shaft with an opening like a shell-hole.
- 2nd. An "à la Boule" shaft with uncovered opening, but narrowed down so as to allow room for the observer's head only.
- 3rd. An "à la Boule" shaft with opening covered by an armored turret or a metal observatory of one of the types described further on.
- 4th. Bomb-proof room with a periscope.

The choice of the arrangement will depend of the object of the post. (Sentinel, artillery observation, etc..)

METAL OBSERVATION POSTS.

Besides the types described in the Instructions on field-works (armored shelters for sentinels, observation sentryboxes) there are three types of metal observatories that can be divided in parts the individual weights of which do not exceed 70 Kgs; so that their transport to the front lines is possible.

They have three observation loop-holes. (Plate 26)

They are placed at the top of a shaft arranged at the end of a gallery.

- 1st. Type S.T.G. (Technical Section of Engineers)

It is a frustrum of a cone in hard cast steel, 0,030 meters thickness, divided into 6 rings and a cap, fitting one into the other. They are held together by four stays passing through the

cap and bolting to the bottom ring. The total weight is 475 Kgs.

2nd. Type "St-James".

It is a frustrum of a cone divided into 5 rings of semi-hard laminated steel, 0,025 meters thick, and a cap, all fitting together. The parts are held together by three stays, between the cap and the bottom ring. Total weight : 380 Kgs.

3rd. Type "St-Chamond".

It is a frustrum of a pyramid of special sheet iron plates 15 m/m thick, divided into 4 sides and a top-piece. The whole is held together by four corner-pieces fastened to the sides and the roof by bolts of special steel. When taking it down for transportation it is best to leave each of the corner-pieces bolted to a side. Total weight : 260 Kgs.

The three types of shelters have been built to resist perforating bullets with steel cones fired at a distance of 30 meters, and even the 37 m/m projectiles, except the last (Saint-Chamond).

Whenever possible a ring of concrete should be formed around the observatory.

Para. 8 - SHELTERS FOR SEARCHLIGHTS, AND OPTICAL POSTS.

The shelters for searchlights vary with the type of apparatus used.

For "35 posts", with-oxyacetylene light, a nearby dug-out will be used to shelter the personnel, with an open air emplacement for the post; for "90" photo-electrical posts" and larger, that have a searchlight and a generator wagon, the wagon will be placed at the rear in a defiladed place, or in a shell-proof dug-out. As to the apparatus itself, a place will be made for it like those for open-air machine-guns, at the end of a shaft or a gallery, depending upon the ground.

An arrangement will be made to conceal the searchlight between hours of duty.

Para. 9 - PROCEDURE FOR BUILDING UNDERGROUND DUG-OUTS.

The Construction of underground dug-outs requires three distinct operations :-

1st. EXCAVATION.

2nd. DISPOSITION OF EXCAVATED EARTH.

3rd. PLACING THE LINING.

These operations must be conducted simultaneously as soon as the progress of the work permits, so that the time necessary to dispose of the earth will be practically the same as that required to excavate it.

1st. EXCAVATION.

The means to be employed necessarily depend upon the nature of the earth to be excavated; the tools that will give the best results are the following :

Ordinary ground)	
	(pickaxes
Clay)	
Chalk	(Pneumatic "picking" hammers.
)	(marteaux-piqueurs)
Hard fissured limestone	(
)	
Hard compact rock	(Hand drills.
)	Pneumatic drills,
	(Electric drills.

The study of the details of these different apparatus is part of the instruction in mines and machinery; only the practical results concerning the compressor plants and the drills are given here :-

A. COMPRESSOR PLANTS.

There are compressor plants of powers varying from 7 H.P. to 95 H.P. (French Horsepower).

Those usually employed on the front are those of 10 H.P., 20 H.P. and 39 H.P.

Those of 39 H.P. can compress 6000 liters of air at atmospheric pressure each minute to 7 kilograms. It consists of

- a) A gasoline motor of 39 H.P.
- b) A compressor
- c) A reservoir of about 500 liters capacity,
in which the air is compressed.
- d) A little 1.5 KW dynamo for ventilating the dug-out and its vicinity (on the last compressors that have been put out).

The whole outfit is loaded on a truck ; the total weight is about 1500 Kgs.

In a new series of apparatus the plant has been divided in two parts, assembled on separate carriages, and easy to put together on the work. This arrangement makes the moving of the apparatus easy. Each of the carriages weighs about 1500 Kgs.

The piping consists of steel tubes (of uniform length = 5 meters; there are two different interior diameters :- 54 m/m and 36 m/m) and rubber pipes (length, 10 and 20 meters; three interior diameters : 40 m/m, 25 m/m and 15 m/m).

The steel tubes must be used in the fixed parts of the installation, and in any case in the immediate neighborhood of the compressor reservoir, as the high temperature of the compressed air,

and the lubricating-oil sucked in would rapidly destroy a rubber tube.

Accessories such as little secondary reservoirs for cleaning out the condensed water, bends, T-pipes, etc. allow numerous combinations in installing a piping system.

The compressor can operate : - 7 "pick-hammers" or 5 drill-hammers, at the rate of 800 liters for each pick-hammer and 1000 to 1200 for each drill-hammer, (from atmospherical pressure).

The hammers will not all be in use at the same time and therefore their number can be practically brought to 10 picks or 8 drills.

The minimum pressure needed to operate either tool is 4 Kgs.

The maximum distance from the working place to the "compressor" is 1800 meters.

The loss of pressure is 1 kilogram per kilometer, approximately.

The installation of a compressor necessitates a concealed shelter, or a simple shed, the dimensions of which must be, for the new machines :-

6,00 x 3,50 x 2,20 meters

It is necessary to have good ventilation in the shelter, so as to obtain a good cooling off of the motor and compressor.

Cost of the group = 50,000 Frs.

Its operating crew consists of :

2 miner non-commissioned officers.

18 miner soldiers.

3 or 4 mechanics.

That is, a total of 23 to 24 men.

The use of this plant will be of real advantage, and its output will exceed that obtained by ordinary methods (picks, hand-perforators) only when the following conditions exist :-

1st. EVACUATION OF THE DEBRIS WITHOUT INTERRUPTING THE WORK OF THE HAMMER.

2nd. IMPORTANT PIECE OF WORK, justifying the use of costly and delicate machinery which takes some time to set up.

3rd. MAXIMUM LENGTH OF WORK AT A SAME POINT, to prevent the loss of time due to the changing of emplacements. These changes usually take quite a long time, particularly when it is necessary to place the compressor in a shell-proof shelter.

4th. CAREFUL ORGANIZATION OF THE WORK, AND REDUCTION OF TIME LOST, in the setting up of the machinery.

5th. GROUPING OF SITES OF WORK, so as to avoid loss of power and to use easily the 10 hammers.

The reduction in length of the piping will also offer the advantage of reducing the chances of a hit by a projectile, and make their up-keep easy.

B. DRILLS. Excavating with the use of blasts necessitates the use of drilling tools such as

MINERS DRILLS AND ORDINARY JUMPER DRILLS.

HAND DRILLS (Guillat and other systems).

DRILLING HAMMERS.

ELECTRIC DRILLS.

The use of electric drills demands the installation of an electric plant, unless electric current is already in use in the places where the work is to be done.

The best electric drills for blasts require 1 H.P.

An electric plant of 6 Kw, frequently used on the front, can operate simultaneously 8 drills, (neglecting loss of power).

2. DISPOSAL OF EXCAVATED EARTH.

To obtain maximum rapidity in excavation, it is necessary to insure the removal of earth without stopping the work of the diggers, so that the quantity removed is equal to the quantity thrown up by the tools.

A/. In the case of digging by hand, the removal can be made by using one of the processes described in the following table. The supposed removal is made in a gallery with a 2/3 slope, ending in a piece of work that is 8 metres deep, and with a personnel permitting continuous evacuation.

To this end, two men have been provided (in the three last processes) at the upper and lower parts of the gallery, to insure a continual loading and unloading, the personnel of the windlass also working without a stop. (This method of removal necessitates at least four small trucks or sleds).

Methods	Necessary personnel	Volume removed per hour.
Relays with shovels	8 men	1 m ³
Sleds and mine windlasses	6 men (2 at windlass 8 men (4 at windlass	0 m ³ 300 0 m ³ 600
Trucks on 0,40 meter rails and mine windlasses	6 men (2 at windlass 8 men (4 at windlass	0 m ³ 400 0 m ³ 800
Carriers suspended on a rail and mine windlasses (1)	8 men (4 at windlass	

(1) See plate 27.)

B./- The above process will be suitable only in the case of mechanical digging. With a pick-hammer, in medium ground, the earth to be removed per piece of work may reach 4 m³ 00, a figure that may be surpassed in friable ground. The evacuation of these 4 m³ 00 can then be accomplished by the use of electric windlasses that pull small trucks on a 0,40 meter track.

The S.T.C. now furnishes electric windlasses of 2.4 HP (220 volts, 8 amperes).

It is necessary in case of steep slopes, to modify the trucks, by adapting wooden pieces carrying a special wooden box, not only to prevent them from turning over but also to diminish their dead weight.

It has been attempted to insure a removal of all the

output of any machine used for digging, by creating the M.O. elevating apparatus. This elevator is a sort of a belt conveyer that is placed in the galleries. (See plate 28).

The belt is carried by a metallic frame, composed of a beam of a $0,60 \times 0,60$ section, and 3 meters long, to which can be added an extension 1,50 meters long.

The beams can be joined together; lengths of 4,50, 7,50, 10,50 and 13,50 are so obtained.

The endless belt is moved by a motive drum placed at the end of the elevator at the entrance side; it is guided at the other end by two drums of a smaller diameter, and is held on the beams by rounded irons.

The motive drum is moved by a 2 to 3 HP. motor, placed in the lower part of the beam. Between the drum and the motor is placed a series of reducing shafts.

The motor receives direct current from an electric plant at 80 volts. The plants used are of 12 Kw; 15 and 20 Kw according to the number of elevators to be worked. Those of 15 Kw can operate 16 elevators

The speed given to the belt is from 0,40 to 0,80^m per second, sufficient to remove all the earth excavated, yet slow enough so that the jars received during the work will not prevent the elevation of round stones that must be removed.

When the materials to be removed are sand or gravel, the belt can be given an inclination of 50 %, with clay 45 %, and with rock 40 %.

The gallery is begun by the ordinary methods, and as soon as two shovel relays are needed to clear the gallery, the elevator is put into place; it is put further down as the gallery advances. This apparatus has the advantage of evacuating the earth from the inside, while the material and personnel are sheltered.

Their use is really advantageous only when the pieces of work are important and grouped together (for instance, to make dug-outs for reserves.

With an electric plant of 15 Kw, 16 elevators can be used along a front of 1000 meters. (Each gallery corresponding to a dug-out for a whole or a half platoon, depending upon the type adopted.)

These devices necessitate a special personnel, and are generally used only by the M.D. Battalions. Their use presents the following advantages and disadvantages :

Advantages.- Personnel and Material sheltered during the work; - large output.

Disadvantages.- It is impossible to use the galleries during the work.- In certain ground taking a flat slope, it entails a greater amount of excavation and of wood for lining, and subsequently, a greater length of vulnerable gallery.

CHAPTER II

As we saw at the beginning, the second condition imposed for underground dug-outs is concealment, even during construction.

It is of the greatest importance in fact, to conceal the dug-outs, not only their openings but also the earth coming from their construction. This will be accomplished :

1°/- By covering the entrances and the plant for removing earth (hand-windlasses, electric windlasses, etc ...) with camouflage

2°/- By taking precautions to prevent the excavated earth from revealing the work. If the subsoil is the same color as the top soil, it will usually suffice to scatter it in the neighborhood.

In the contrary case the following methods could be used :

a)- Filling up shell holes, abandoned trenches and communication trenches.

b)- Filling up small gaps made in the neighborhood of the dug-out; a good method in the case of a dug-out very near the enemy; this would allow the earth to be removed in the day time without any apparent movement of earth.

c)- If a track of 0,40 meters is available, if there is a large number of auxiliaries, and if the defilade allows it, the excavated earth could be used to build, at a great enough distance, dummy works the parapets of which could be made of the removed earth.

CHAPTER III

LIVING CONDITIONS IN UNDERGROUND DUGOUTS

To have the occupants living under the best possible conditions in an underground dugout, it is not enough that it offers protection in case of a bombardement, and, by a judicious interior arrangement, a possibility of short rest. It must be also possible for the occupants to live there for a long enough time and it is essential that the dug-out should be made as wholesome as possible, from the point of view of humidity and that of ventilation.

A/- SANITATION.-

The sanitation of the dug-out must be one of the most important considerations of the engineer-officer in charge of its building. It is certainly not a rare thing to see on the front many flooded and abandoned dug-outs, that took a considerable effort to build, and that are more often invaded by rain water than surface water.

One has to fight against infiltrating water very much on the two shores of the MEUSE, especially on the right bank, where the dug-outs are built in a fissured limestone. In these regions, where the soil is much turned over, the rain water gathers in the shell-holes, and through the fissures in the limestone penetrates little by little to the body of the dug-out, that is before long a regular cistern.

In this terrain, it is best to use blasts with great precaution as they increase the fissures and the seepage.

Rain water may be fought by the following processes :

1°/- Establishment on the surface previously marked off, of a slightly inclined cover of tar-paper, or light corrugated sheet-iron.

(This process, very vulnerable, does not completely prevent rain water in deep dug-outs).

2°/- Making of two saw-cuts on each vertical side of the cap-sills, with a slope of about 1/10, depending on the length of the cap-sill, of 1 cm in depth and slightly inclined upwards.
(Plate 29).

Into these cuts are wedged light sheets of corrugated iron, fastened with wire. A longitudinal gutter "G" catches the water and turns it towards a sump placed at the end of one of the galleries. The sump is covered by a wooden grating, and emptied by a pump.

3°/- Another process consists in establishing a gutter parallel to the cap-sill, and fastened to it by clasps of sheet-iron.

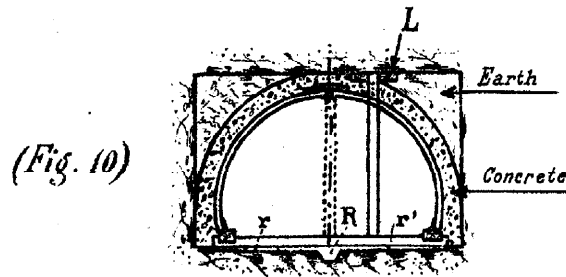
The iron-sheets, sloped, like the 1/10 gutter in a transverse direction, rest on their edges and turn the water into a longitudinal gutter. (Removal of the water as in the 2nd example).
(Plate 29).

4°/- An arched form can also be given to the sheets, to turn off the water into two longitudinal drains. (Plate 29)

5°/- Let us mention another method that has not yet been proved by experience, but that seems susceptible of rendering service from the point of view both of sanitation or of reinforcement of the dug-out in the case where the presence of a water bearing stratum does not permit of obtaining the necessary cover against large caliber shells.

The dug-out will first be built as a grand gallery with a common gallery parallel to it. After replacing the two adjacent stanchions, the cap-sills remaining held by two cross-pieces "L", a sheet iron arch will be placed in the body of the dug-out, propped under the center and the spaces between the sheet iron and the walls filled in with concrete as the work goes on.

The seep waters will be conducted by transversal drains "r" and "r'" towards a longitudinal drain "R" inclining towards a sump placed at the end of one of the entrances (Fig. 10)



B/- VENTILATION

The airing of a dug-out will be assured, either by an "à la Boule" shaft opening in the wall of the body of the dug out, or more rapidly by the use of ventilating chimneys made with the use of "Guillat" hand-augers. This auger both simple and rapid in use, can make vertical holes of 10 to 12 meters in length and 15 cms

in diameter in 6 to 8 hours time in medium ground. (1)

When the importance of the organization, the number and capacity of the dug-outs justify it, ventilation and electric lighting can be realized at the same time.

In one of the recesses of the dug-out a 3 Kw. D.C. Electric Plant and a 110 volt electric ventilator will be placed side by side. (The ventilator could eventually be worked by hand).

The exhaust from the engine could be removed a sheet-iron pipe leading to the outside through a shaft.

LIGHTING.

Two insulated power-supply cables will be used for transmitting the current to the points of using; from these cables branches will lead to 16 candle-power lamps (metal filaments preferably).

The lamps will be placed at convenient points in the dug-outs, generally on the bottom of each entrance, and one for each recess. (See plate 19 giving an example of an arrangement used in the Verdun region.)

VENTILATION.

The ventilation will be had through a vertical duct directly over the ventilating fan; the air will be driven out through a 0,12 meter piping, suspended to the ceilings of the passage galleries.

(1). - The Central Engineering Establishment has tubes of 0,15 meters at its disposal, for maintaining the shape of these holes.)

The air will be distributed by adjustable dampers, placed when needed in the air-pipes.

The installation must take the necessary precautions for insulating (insulated wire, porcelain cleats, etc.); a ground indicator will be established to let the mechanic know at all times the state of insulation of the system.

The 3 kw. electric plant in action for 12 hours out of 24 is sufficient to operate 64 16-candle lamps and 2 ventilators.

CHAPTER IV

PROTECTION AGAINST DELETERIOUS AND ASPHYXIATING GASES.

Protection against gases is met by different processes :

1°/- cloth curtains obstructing the entrance or doors closing as tight as possible.

2°/- Drums closed by two curtains suspended from frames placed at the entrance galleries 2 meters apart (See plate 30.)

A man placed in the drum neutralizes, with a spraying machine containing an appropriate solution, the gases that can penetrate in this space, whenever the exterior curtain is lifted to allow some one to pass.

The rounded form given to the uprights of the frames allow the curtain, stretched by a metal brace, to fit very exactly against these uprights.

The interval between the frames and the wood-works of the gallery is closed by a wall of sods.

These two methods are rough ones; they are certainly insufficient against the prolonged action of gases.

3°/- Previous system completed by a filtering gallery.

If the emission of gas is of several hours duration the interior volume of air necessary to assure the life of the personnel in the dug-out will be insufficient, and it will be necessary to have an arrangement allowing the removal of the vitiated air. To

that effect, the absorbing power that vegetable earth has for noxious gases will be used, by creating in a gallery specially built for that purpose, an earth filter through which the air will be drawn. Ordinary earth can hold about its own volume of chlorine gas; that is one cubic meter of this earth can hold under a wave of attacks, given the usual concentration of such waves, at least one thousand cubic meters of breathable air, at a maximum speed of 1 m³ by minute. The earth being arranged in a 50 cms. layers, that is 2 square meters of surface per cubic meter put in place, this output will be obtained under a difference of pressure of 2 to 3 centimeters of water.

The fresh air drawn in by the ventilator will expand in the rooms and create an over-pressure that will favor the expulsion of the gas at the curtained entrances.

Again, the quantity of air necessary per minute is :

For an Infantry section = 1 m³.

Additional for each opening = 1/2 m³.

For instance, a dug-out for 1/2 platoon having only one outlet will be sufficiently ventilated with 1 m³ per minute; if there are two openings, 1.5 m³ will be needed.

If it is a question of a C.P. or a dressing station,
the calculations will be made on the volume of the dug-out, counting 1 m³ of air per 100 m³, plus 1/2 m³ per opening.

The thickness of vegetable earth must be about 0,50 meters, and with a sufficient density obtained by tamping, there will be counted, for the normal capacity of the filter in one

minute, $1/3 \text{ m}^3$ of air per square meter of surface.

The surface of the filter for a dug-out of half a platoon with one opening will thus be 3 m^2 ; for a C.P. of 100 m^3 with openings, 4 to 5 m^2 .

The filtering gallery can be made in prolongation of the dug-out. It can also be placed parallel to the body of the dug-out, separated from it by a thickness of fresh earth of at least 3 meters, and opening into one of the entrance galleries. (Plates 31 and 32)

This last disposition seems the most advantageous as it is independent of the body of the dug-out and allows an easy upkeep and watching of the filter.

In both cases, there is need of obtaining, in building the filter and placing the ventilator (1), a complete closing of the joints with vegetable earth, so that the ventilator cannot draw in unfiltered gas through the fissures.

A dozen realistic trials of this system have been made, either at Satory or in the Army zone; and have given satisfaction : under toxic atmospheres much more concentrated than the attacking waves, the air of the dug-outs has remained pure for 7 consecutive hours, notwithstanding the more or less numerous exits and entrances; occupants were able to remain without using masks and without being disturbed. Nevertheless, this method of protection against gas cannot be actually considered as completely proved, by experience.

(1).- Plate 33 gives an example of a wooden ventilator constructed for the division or army corp C.P.'s.)

SECOND PART.

SURFACE SHELTERS.

CHAPTER I.

SHELTERS FOR PERSONNEL, MACHINE GUNS, C. P. OBSERVATION STATIONS.

1.- GENERAL VIEWS

Surface shelters for field works proof against high-power 210 projectiles (1) can be built :

1°/- Entirely in masonry, (an exceptional method because of the great protective thickness needed), or entirely in special concrete, or entirely in reinforced concrete.

2°/- If the body of the shelter is in masonry and already existing, by making reinforcements that will include a mattress of sand and broken rocks and a burster (Reinforcing of a cellar for instance).

- (1).- In case it should be necessary to obtain protection against higher calibers than 210, and when it is not feared to make a strong "relief" on the surface of the natural ground, the type of "interior revetment" will be used, with a bed of sand and bursters as recommended by the "Note of August 23rd 1916, from the G.Q.G. following the report of Lt-Colonel BENOIT, on the effects of the bombardment of the fortifications of VERDUN.

This last mode of construction is to be recommended if there are materials for masonry (coming from : quarries, ruined houses or villages) on hand, not far from the site of work. Then we will only have to provide the materials necessary for the bursters and mortar for the masonry.

The shelters proper will be composed either of large capacity main shelters, or better of a series of recesses opening on a central or lateral passage way.

The interior lining will either be made by strong sheet iron arches or by mine gallery frames.

In the building of a surface shelter, the following principles should be remembered :

1°/- To diminish the height above the ground level, and to give greater protection, the dug-outs will be sunk as deeply as possible into the ground, without going below a depth of 3 meters, as that would necessitate considerable excavation.

2°/- The exterior form of the parts exposed to direct hits from artillery fire must be rounded off and flattened to increase ricochetting.

3°/- The upper covering of concrete roofs must receive only a thin layer of earth or sods, to avoid tamping.

4°/- Whenever possible, make independent the burster and the main body of the shelter, so as to diminish the amount of static strain that the last will have to support.

5°/- Except in special cases, the lining composed of sheet iron arches or mine-frames, will be maintained after the completion

of the concrete and the masonry. This lining will make the interior fittings easy to build; it will help to make the construction stronger, as there may be imperfections therein because of the difficulties that will be often met in constructing these works at the front.

6°/- In arrangements consisting of slabs resting on abutments, make a very good joint so as to prevent what happened at VERDUN, that is, sliding with reference to one another.

2. - SHELTERS FOR PERSONNEL.

1°/- Shelter with a sheet iron arch body. -

Protection may be obtained, as shown on plate 34, either by a special concrete shell 1,50 meters thick (with an apron), or by a slab of reinforced concrete 1 meter thick resting on broken stones; or by an interior lining in masonry 1 meter thick (or of special concrete 0,50) covered with a 1 meter mattress of broken rock and a 0,75 meter burster of reinforced concrete.

The beds are placed side by side perpendicular to the axis of the shelter; the outlets are of common gallery dimensions.

2°/- Body of a shelter of grand gallery dimensions. (See plate 35)

Protection may be obtained either by a lining of 0,50 meters of special concrete covered with a 1 meter mattress of broken rock and a 0,75 meter burster of reinforced concrete, or by a special concrete shell 1,50 meters thick (with apron), or by a reinforced concrete shell 1,00 meter thick (with apron), or by reinforced concrete slab 1 meter thick supported by abutments of 1,25

meters, made of masonry, and held together tightly by cross-bars.

The beds are placed parallel to the body of the shelter in the middle of which a 0,70 meter passage is left; the outlets are of common gallery dimensions.

3°/- Body of a shelter composed by recesses opening on a central or lateral passage.-

The recesses can be made with sheet iron arches (Plate 36) holding 8 men, or be built like grand galleries (Plate 37) holding 6 men.

In both cases, the protection of the shelter may be obtained by one of the methods indicated in the two preceding cases.

The passage is built as a common gallery or a 1,33 meter gallery. The outlets are built of a common gallery size ...

3 - POSTS OF COMMAND -

DRESSING STATIONS.-

These are constructed after the same principles as the shelters for personnel (type with recesses and central hall) and only differ as to the interior arrangements. (See the underground dugout, C.P.'s and dressing stations, pages 22 - 31)

They will be generally built into a slope facing away from the ennemy, the different rooms receiving daylight through loop-holes made in the wall.

4.- MACHINE GUN SHELTER.

Types formed by only one slab or elliptic vault supported by abutements will usually be adopted for surface shelters for machine-guns.

1°/- SHELTERS BUILT OF RAILS AND SPECIAL CONCRETE. - (Plate 38).

The roof is composed of two crossed rows of rails separated by a 0,50 meter layer of concrete, and the whole is covered with a 0,10 meter thickness of concrete, so as to form a slab 0,90 meters thick. The abutements are 1 meter thick. This shelter is hardly proof against a high-power 210 shell.

2°/- SHELTER OF " Casemate de Bourges " TYPE. (Plate 39).

The parts exposed to direct hits, that is, the roof and the wall facing the enemy in which the embrasure is cut are made of reinforced concrete. The shelter has a lower story reserved for the personnel. The front wall is 1,50 meters thick and the roof 1,75 meters; the relief is about 2.80 meters; it is a type only to be undertaken when the emplacement is hidden from the enemy's view. The construction necessitates a big concrete working plant; but the finished shelter is proof against high-power 210's and 305's and there is need of reserving it for machine-gun positions having a fundamental defensive role (covering a point that must be passed, general enfilading position, etc ...)

3°/- The two types that have been described have the inconveniences of being a large size and showing a high relief. The relief is a condition that cannot be entirely avoided, as it is necessary to

have the axis of the embrasure at least 0,30 meters above the natural surface of the ground, and subsequently the lower part of the slab will be at least 0,70 meters above the level. For reinforced concrete shelter proof against high power 210 shells, the minimum relief is necessarily 1,70 meters.

this is the thickness of the casemate shown on plate 40. Besides this, the interior dimensions of this casemate have been considerably diminished by an arrangement of the front wall for holding the front part of the tripod, and by a reduction of the positions of the marksman and the loader. (1).

The personnel is protected in normal times in an underground dug-out joined to the casemate by an entrance protected for several yards by a block of concrete.

Whatever type is adopted, it is essential to build all these casemates only at points where they cannot be observed (counter-slope line, wooded region, 2nd positions, etc...) and it is necessary to disguise them carefully (camouflage).

Otherwise, in spite of all the care used in their construction, they would be liable, because of their relief, to a certain destruction, if the ennemy wishes to pay the price, because the repetition of hits will bring about a disintegration of the concrete. Furthermore if the shelter itself is spared, the earth thrown up in front of the loop-hole will make the machine gun's action impossible.

(1).-- the front dimensions of the casemate could be reduced still further by using the automatic loading arrangement described further on.

°/- ARMORED CASEMATE.-

It has been attempted to diminish the relief, and consequently the visibility, by using metal roofs.

The type shown on plate 41, which has already been used (2nd Army) is composed of semi-hard steel cap fitted into a reinforced concrete block. The thickness of the cap varies from 110 m/m at the loop-hole to 80 m/m at the rear.

The machine-gun is placed on a special support that can turn around a vertical pivot placed in its forward part; in this manner the machine-guns pivot around its muzzle, taking up less room and needing a smaller loop-hole. A special arrangement forms a sort of a "depression-carriage" allowing the machine-gun to be brought back and allow the loop-hole to be closed.- The horizontal field of fire is 90° in a casemate with 1 loop-hole, 150° in one with two loop-holes.

The camouflage of these casemates is very easy the visibility is practically nothing.

°/- A MINIMUM EMBRASURE.-

The visibility of machine-guns can also be diminished by reducing the size of their loop-holes to a minimum (for a wall 1 meter thick and a field of fire of 60°, the size of the opening at the exterior must be 1 x 0,30 meters). This result can be obtained by a recess in the wall where the machine-gun will be placed, and by fixing it on a special carriage that can be moved about on a circular track "C". The automatic loading is effected by a drum that is part of the carriage, and whose place is perpendicular to the ma

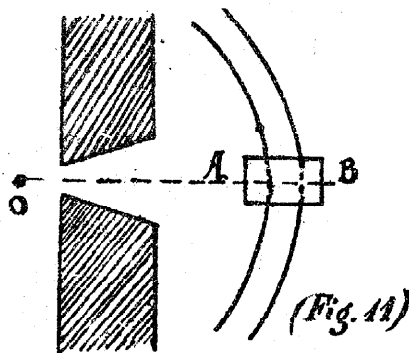
chine-gun in all its positions. Each drum can hold 500 cartridges.

(See plate 42).

An opening in the concrete wall is made to have room for the drum when the machine-gun is in its extreme position.

This method has the inconvenience of diminishing the protection of the machine-gun and its crew. To counteract this a method has been tried in the 2nd Army that allows the machine-gun placed inside the shelter to pivot around an imaginary point placed on the outer covering of the wall.

This arrangement is composed of : - 2 circular rails, the center "O" is a little in front of the outer wall of the casemate (Fig. 11)



On the track is a special carriage carrying the machine-gun A B.

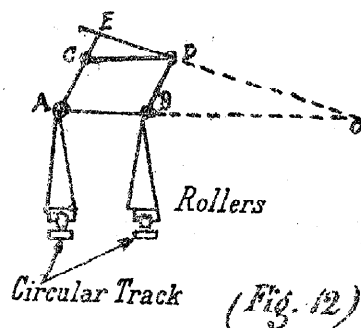
By moving the carriage on the tracks the arm acts as if it was prolonged to the point O around which the fictitious muzzle pivots.

In this way a minimum opening is obtained, in a horizontal direction.

A minimum in a vertical direction is obtained by a special construction of the carriage.

The machine-gun is fastened to the carriage by means of an articulated parallelogram, that allows the arm to be lowered or raised as desired, by making its prolonged extremity pivot almost

around the same point "O". (Fig.12)



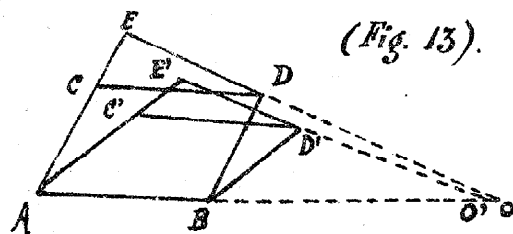
In this manner the outer opening of the loop-hole can be reduced to a few centimeters in height.

The carriage which can be taken apart is built of iron rods mounted on rollers that run in the tracks.

The upper part of this construction forms the side AB of an articulated parallelogram ABCD on which the arm is placed through an intermediary plate DE, movable around a horizontal axis at D and resting on the prolongation CE of the side AC, that terminates in a roller.

In the apparatus the side AB is immovable, the lengths AE and BD are constant.

When the parallelogram is deformed (ABC'D') the plate



DE still rests on the prolongation of AC that has come AC'E'. The line E'D' cuts AB in a point O' which coincides with a point O (fig. 13).

In fact, we have by the similar triangles :

$$\frac{O A}{A B} = \frac{A E}{A E - B D} = \frac{A E}{C E}$$

$$\frac{O' A}{A B} = \frac{A E'}{C' E'} = \frac{A E}{C E}$$

$$\text{and thus } \frac{O' A}{A B} = \frac{O A}{A B} \quad O' A = O A$$

As A has not moved O' coincides with O.

Ventilation of the casemates.-

The combustion of the powder in the cartridges gives a great quantity of oxide of carbon that spreads in the shelter and may rapidly poison the personnel : the fact has been verified. And so it is necessary to secure a good ventilation of these shelters.

5 - OBSERVATION STATIONS.

The observation stations are of a type similar to machine-gun shelters, but as small as possible to diminish their visibility.

Observatories for commanding officers and artillery must frequently be built on the front; these two should be separated so that in time of battle the services will not interfere with each other.

The observatory can then be built as indicated on plate 43 and consist of two small observatories in reinforced concrete joined underground by a dug out and containing beside two telephone stations (1 for artillery, 1 for infantry) the lodgings of the personnel (telephonists, observers) that of the Artillery Officer and that of the Staff or Infantry Officer.

The details of the observatory proper are given on plate 43 that shows it with either shaft or trench entrances.

It holds two or three persons, but the interior dimensions can be reduced if desired.

CHAPTER II.

SPECIAL CONCRETE AND REINFORCED CONCRETE.

Special concrete and reinforced concrete are made with gravel, sand and cement; the proportions of these three elements are the same in each variety of concrete. Reinforced concrete differs from special concrete only by the metal bars embedded in the mass.

The resistance of concrete depends entirely on the proportions, the choice of materials and the care of placing it.

1 - PROPORTIONS.

The following proportions will be used :

Gravel : 0, m³ 900

Sand : 0, m³ 300

Cement : 400 Kgs.

This proportion will give 1 m³ of concrete put into place.

If instead of gravel, broken stone and slag are used, the volume of sand must be brought to 0 m³ 350. to obtain a solid concrete.

In reinforced concrete the weight of the metal must reach 80 Kgs per m³, this weight corresponds to the maximum strength.

2 - CHOICE OF MATERIALS.

A/- SAND. -

The sand must come from very hard rocks, as far as possible silicious; its grains may be rough or smooth; it must be completely free from clay and all foreign matters; it must grate in the hand; it must be washed with great care; the largest size of the grains must not surpass 1 centimeter.

The sand must therefore be sifted with a sieve of one centimeter square mesh, but too fine a sand (less than 2 millimeters) must not be used. The sand may be advantageously used as it comes (fine and large grains) sifted as stated above.

B/- GRAVEL.

Gravel or a mixture of pebbles coming from hard rocks or very hard materials only must be used. The rocks or materials must be also very dense (granite, porphyries, flint, silicious rocks, slag from smelting furnaces, etc.) excluding soft limestone, porous sandstone, etc. The gravel may have the form of shingle, broken stone or very hard slas. It is not necessary that the size of the elements be the same; it can vary from 2 to 7 centimeters, but a mixture containing a strong proportion of elements of the largest size should be preferred.

The pebbles going through a sieve with 7 centimeter spaces between wires can be used. They must be freed from all foreign matters dirt, sandstone, etc.

C/ CEMENT.

For works in special reinforced concrete slow setting artificial Portland cement of a very good quality must be used, it must not have been injured by exposure to the air, and must not

contain lumps that have hardened already.

For works of limited duration Puzzolana (Slag) cements may be used, but they have the disadvantage of sometimes attacking the metal and of losing strength in time when they are used in open dry air.

The resistance of mortars and concrete of slag cement is about 3/4 of that of mortars and concretes of ordinary Portland cement of the same proportions.

Quick setting cements should be avoided because of the difficulty of handling and because they are not as strong as slow setting cements.

Among slow setting cements answering to the above conditions, finely ground cements that harden very rapidly are chosen, as their mortars have three days after the mixing a far greater strength than the mortars of ordinary cements after seven days.

Lastly to obtain a rapid hardening with slow setting ordinary Portland cement, chemical products such as chloride of calcium (100 gr. per litre of mixing water) can be put in the water used in making the concrete. This process has not been sanctioned by practice.

U/- STEEL:-

The bars for the reinforced concrete of defensive works usually consists of round bars in extra soft steel the diameter of which vary between 10 and 20 millimeters; if round bars are not available, square or half flat steel bars can be used; the concrete can be reinforced even by using rails as indicated hereafter. Lastly,

semi-hard steel bars can be used on the condition that this steel is not brittle and that it can support the strain of bending while cold that these bars have to be submitted to before being placed in the concrete.

3 - PLACING THE BARS IN REINFORCED CONCRETE.

The thicknesses of blocks of reinforced concrete, as well as the number of bars, have been experimentally determined to insure the resistance of dynamic efforts produced by projectiles; the total sections of steel that are the result of these determinations will provide an excess of strength against static forces, in the usual conditions of construction of concrete shelters.

It is best to subdivide the steel and to distribute it thoroughly in the concrete, so as to increase the homogeneity and to make uniformity of strength in the whole mass.

To that effect, it is better to use a large number of small rods than a small number of large ones.

A₁ - Arrangement of metal bars for arches or horizontal slabs. (Plate 45)

The average proportion of metal must be 80 Kgs. per cubic meter of concrete; this condition will be achieved by incorporating horizontally placed grillages in the concrete; the successive grillages will be separated vertically by 0.15 meters, each grillage will consist of 10 m/m bars laid in squares of 10 centimeter sides. If 10 m/m bars are lacking frame works made of larger bars may occasionally be used; the dimension of the squares and the

space between grills is then enlarged so as to obtain a weight of 80 Kgs. of metal per cubic meter of concrete; but the resistance of the block is then less for a same weight of metal than it should be if built with 10 m/m bars laid as has been described.

Lastly, the reinforced concrete slabs or arches can be greatly reinforced, by sinking in them beds or rails or metal beams. The rails must not touch each other, they must be spaced so as to leave 0,10 meters width between each other into which the concrete will penetrate, a union is thus obtained between the two layers of concrete that are on either side of the bed of rails. When the rails and beams are placed side by side, continuous planes of weakness are created, where sliding and cracking may be expected.

The beds of concrete are also reinforced with 10 m/m bars made into grillages so that, except as regards rails, the density of the metal remains equal to 80 kilograms per cubic meter of concrete.

If several layers of rails are made, adjacent layers are separated vertically by a multiple of 0,15 meters and are laid perpendicularly to each other.

The grills are placed horizontally, even in the arched covers.

B/- Arrangement of metal frame for covering very steep galleries.
(Plate 45)

The percentage of metal, the sections of frame work, the size of the squares, etc.. described above are adopted, but the grills cannot be placed in a horizontal plane, because they would be in an unfavourable direction for resistance.

As it is impossible to pour the concrete down the very steep slope of the gallery, the grills cannot be placed parallel to the longitudinal axis of the gallery, so they are given a 1/4 slope, and this same slope is given to the tamped surface of each layer of concrete.

C/- ARRANGEMENT OF METAL WORK IN REINFORCED CONCRETE WALLS.-
(Plate 45)

Walls of reinforced concrete exposed to artillery fire whether protected or not by a thick mound of earth and piles of rocks, must have the following metal-work :

1°/- In each surfacing of the wall place a vertical grill with squares of 0,15 meter sides and built of horizontal and vertical bars of 1 cm. in diameter.

2°/- On the exterior surface only, place two vertical sheets, parallel to the surfacing, and formed of rods 2 centimeters in diameter spaced 0,30 meters apart in each sheet, these sheets are respectively 0,15 meters and 0,30 meters from the exterior surface; the bars of the two sheets are staggered.

All these 2 cm. bars are prolonged at their upper part so as to penetrate as far as possible in the arch or in the slab carried by the wall.

3°/- Throughout the entire height of the wall, place horizontal grills with squares with 0,15 meter sides spaced vertically by 0,15 meters, and formed of bars 1 cm. in diameter.

It is well to remember that if the wall is not protected, the frame-works will hardly furnish the resistance against several

isolated hits.

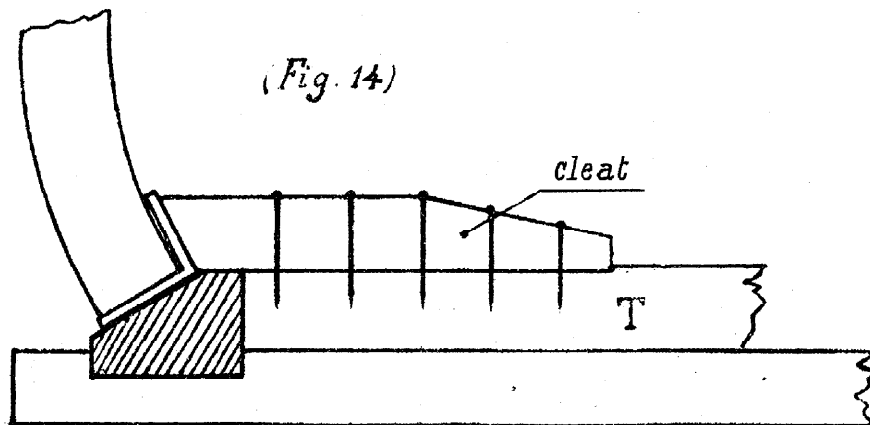
For reinforced concrete walls that are not under artillery fire, or that are protected by a great mass of rock-work, the frame-work can be simplified.

EXECUTION OF WORK

para. 1 - FORMS FOR CONCRETE.

10/- As we have already seen, the forms for shelters of personnel will usually be made of sheet-iron arches or wooden frames.

The sheet-iron arches will be reinforced by a vertical strut upholding the key, the horizontal reinforcement will be completed by a cross-piece T placed between the two ground sills, whose separation it assures. (Fig. 14)



In a case of a well defined direction of dangerous hits, the body of the dug-out will be still more reinforced by an oblique prop, placed as indicated by plate 34 (two meters apart so as not to disturb the bed-arrangement).

In the linings of galleries, dug-outs or passage ways, the frames will be placed 0,50 meters apart center to center.

The frames of grand galleries will be reinforced and cross braced every two meters by an arrangement similar to that in plate 35.

2°/- The forms may be movable, for example in the construction of observatories, casemates for machine-guns, etc..

In this case they will be formed by bolsters resting on beams, supported by props. The bolsters will be built of planks; they will be laid close together to prevent mortar from running through but must allow the dripping of water driven out of the concrete during the tamping and setting.

The distance apart of beams will be determined by the thickness of wood used for the bolsters; the number and placing of cleats will depend on the dimensions of the beams. The wood-work of the forms must be given a great strength and a sufficient rigidity, so that setting or deformation need not be feared, caused by moving of the materials over them, by an energetic tamping of the mortar, or by the load imposed by the mass of concrete.

To facilitate the removal of the forms and re-utilization of the timber, it is best to rub black soap on the surfaces of the bolsters in contact with the concrete, and the props will be placed on wedge blocks.

Lastly care will be taken when building the forms to make marks at the elevation where the metal grills are to be placed.

Para. 2 - PREPARATION OF THE MATERIALS.

a/- Preparing concrete on the mixing-board.

The mortar is first prepared, and then it is mixed with

the aggregate to make the concrete. For making mortar, a dry mixture is first made of sand and cement, so that a well mixed mass is obtained then little by little the proper quantity of pure water is added so as to obtain after mixture a mortar of proper consistency. The quantity of water depends on the temperature and the dryness of the sand. The mixing is first begun with a weight of water equal to 25% of the weight of the cement. Then water is added till the proper consistency is reached; the mass has a good consistency when a piece of mortar taken and squeezed in the hand is easily given a form of a ball., and oozes water slightly, and when a ball of mortar of 3 or 4 centimeters in diameter, falling on a floor, takes a convex and uncracked form.

It is best to have available at least 150 litres of water per cubic meter of concrete to be made ; this provision does not comprise the water necessary for washing the aggregate, or for dampening the surfaces of the forms, etc.

The mixing of the mortar is made with hoes and shovels on a mixing board made of heavy planks, on small jobs otherwise mixers are used.

For preparing the concrete, the gravel is mixed with the mortar prepared as above; the gravel is wet, but completely drained off before being mixed with the mortar. The mixture is made on a mixing board, with shovels and hoes for small jobs; and only $1/3$ cubic meter is mixed at one time. For important work mixers are used.

b/- Preparing the metal work.-

All the bars have on their end a hook the opening of which

is equal to four or five times the diameter of the bar. When a bar is too short to go from one side to the other of the frame-work, the length is completed by two pieces placed in extension of one another, furnished with hooks at each end and over lapping a distance equal to thirty times the diameter of the bar.

The hooks on the bars are made while cold; labor is so economized and the metal is tested. To do this a bench and levers are used; a lever 2 m.10 long, used by two men, allows the cold bending of steel bars 25 m/m thick; with a clawed crow-bar 0,75 long, bars of 10 m/ms can be easily bent. (Plate 46.)

The metal rods should be cleaned with a wire-brush, as far as possible of rust and mortar; it is necessary for them to be clean; adherent rust presents no objection. The rods are cut according to the lengths shown on the plans (hooks included); To simplify cutting, standard lengths that vary by 10 centimeters are adopted.

When the rods are bent, they are piled up on the ground each length in a distinct pile; in this way errors and loss of time are avoided.

Para. 3 - PLACING OF THE CONCRETE AND OF THE METAL.

The placing of the concrete is done in the same way for special or reinforced concrete.

When wire netting or expanded metal is available a continuous sheet of it is placed on the forms, this netting prevents small particles of concrete from flying away under the action of projectiles.

Above this netting the first grill is placed, and they are bound together by numerous wire fastenings.

When the grills that must be used in the concrete have a small surface, they can be built beforehand on the ground, by fastening the bars together with wire, and then placing them as one piece when the concrete is at the proper level for their use.

If on the contrary the frames are too large for transportation, they are built up on the concrete that has been flattened off at the proper level.

To place the bars at the proper width and to hold them there during the placing of the concrete, notched battons may be used.

The bars that follow the edges of the frame are shoved through the hooks of the bars that end at those edges.

In the distribution of bars vertically care is taken to place the upper frame flush with the upper lining that serves as coping and it will prevent its cracking. In case of an arch one of the frames must be tangent to the crown.

When the first frame is in place the pouring of the concrete is begun.

If the mixture settles during its transportation to the work, it must be given a new mixing before pouring it in the forms.

This pouring is made by 0.15^m layers, that is a thickness equal to the vertical distance between successive grills.

The upper part of the last layer put in place, that will consequently form the extrados of the arch or of the slab, can be

made richer in cement and of fine gravel (600 Kgs. of cement per m³ of gravel), so as to make a surface (levelled with a flat tamp and smoothed with a trowel) that assures the water tightness of the cover. The tamping of the concrete is made with 15 kilogram rammers (1) or compressed air tamps (pillettes); it must be done energetically and carried far enough to make a sheet of mortar flow to the surface, in which the metal bars will be placed. The adherence between the bars and the concrete will thus be assured. Concrete formed by broken rocks will need a longer tamping than that made with gravel. The excess of water in the concrete diminishes the strength, lengthens the time of setting and makes the tamping difficult because the concrete slides from under the rammer; besides this, the dripping out of the excess water produces vacuums in the interior of the mass.

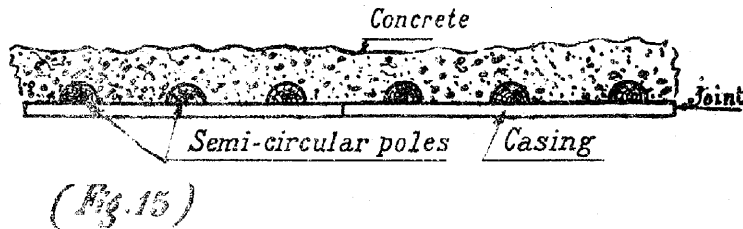
On the contrary, too dry a concrete hardens too rapidly, is less bound to the succeeding layers and produces a porous and un-homogeneous mass.

The making of a block of concrete must be as much as possible without interruption, so as to avoid joints; beside this, each layer of concrete must be covered with a new layer before the preceding one has set, that is about three hours.

If the block of concrete cover occupies too large a surface to allow an uninterrupted pouring it is divided into parts

(1).- In reentrant angles or in pieces encumbered by the metal bars, the tamping is effected by pinching-bars (pieds-de-biche) that are worked between the rods.

that are separated by vertical joints. Their surfaces are made with projections so as to assure the joining of the adjacent blocks, for example with half round strips fastened to the forms that form the joint. (Fig. 15).



If interruption in the work cannot be avoided the surface of the concrete that has already set must be cleaned of all loose pieces, thoroughly washed and coated with pure cement; the layer must be given a very intense tamping.

Any concrete that has begun to harden on the mixing board must be thrown aside.

The concrete must be kept damp until it has started to set. Avoid leaving it under the direct action of the sun's rays; it must also be protected from freezing by a covering of straw, of tarpauline, of sacks, etc ...

The placing of concrete may be made in a moderately cold weather. (Temperature near 0 degrees centigrade).

Para. 4. - REMOVAL OF THE FORMS.

The forms must not be removed too soon, as the strength of the concrete during the first weeks is a very small fraction of its final resistance.

The strength in compression at the end of 28 days is only 44/100^o of its strength at the end of a year.

Nevertheless, because of the great relative thickness of the arches or the slabs, that is greatly superior to that that would be necessary to support the static forces, the removal of the forms can be made, even in the case of special concrete, ten days after the concrete is put in place, if dynamic effects are not immediately to be feared; it can be done in an even shorter period, if the block of concrete contains one or two layers of rails.

THIRD PART.

SHELTERS OF MEDIUM PROTECTION.

We have seen that in field works, although generally necessary to seek protection against 210's, there are cases when we must be contented with a lesser protection.

The shelters so constructed will be mostly made of a lining of wooden frames or sheet-iron arches covered with a protective mass, for the establishment of which the following principles should be remembered :

1°/- A layer of logs of 0.15 to 0.20 meters diameter, well fastened together, placed on the surface of the natural earth, and covered with 1 meter of earth, is equivalent to 1 meter of natural earth. (MAILLY).

2°/- A layer of fresh turned earth offers about half as much resistance as a layer of natural soil of same thickness.

3°/- It is essential that the construction be made so that the greater part of the protective mass does not bear on the body of the shelter; the value of the static efforts it will have to support will thus be diminished, and it will be in better condition to resist the dynamic efforts caused by the explosion of projectiles.

4°/- The resistance of the shelter will be considerably increased by the adding of a shell-exploding layer (bursting)

formed of logs, rails, metal beams, sacks of cement or concrete, strong iron sheets, layer of stone or bursters.

These slabs can be furnished from the Engineer Yards, or they can be easily built on the spot by Engineer troops.

They are certain elements of reinforced concrete that are assembled on the spot by metal clips fastening the iron rings at the corners, so as to make a continuous exploding blanket.

The usual types are the D A I and the VERDUN types.

(See plate 47).

Composition :	{	400 litres of sand
	{	800 litres of gravel 0.024 m^3
	{	400 Kgs, of Portland cement.

Weight of the iron : 6 to 7 Kgs.

Weight of the slab : about 90 Kgs.

If the dimensions of the slab are reduced to 0.45 x 0.45, the weight will be reduced to 60 Kgs. if the above amount of gravel is used or 45 Kgs. if the gravel is replaced by iron slag.

If time is lacking, Portland cement can be replaced by grout (ciment fondu) that sets in three days.

The connections of the slabs are made of very soft steel loops of 10 m/m and 0,60 meters long, closed by twisting. To increase the strength of the exploding layer, two layers of slabs may be superposed. It is well to separate the two layers by a thickness of about 30 cm. of earth, to favor the deflection of projectiles by passing through different materials.

Protection against 105's and 150.-

It can be admitted that shelters are proof against 105 shells when they comprise :

A bed of rails or joined logs covered with 1 meter of earth, with an upper burster, and that they are proof against 150 shells when they comprise :

Two layers of rails or logs separated by 0 m 50 of earth and covered with a layer of earth topped by a burster.
